DRASTIC Hydrogeologic Settings Modified for Fractured Till: Part 2. Field Observations[1]

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ABSTRACT. **Developed as a companion paper to "DRASTIC Hydrogeologic Settings Modified for Fractured Till: Part 1. Theory," twenty-one field sites around glaciated Ohio were visited to determine if fractures were present in the soils and underlying parent materials at each location. Four sites were featured with in-depth discussions. In all, 23 of the original 95 fractured soils identified in Tornes and others (2000) were confirmed in the field and four new soils were added to the list: Amanda, Avonburg, Blanchester, and Clermont. Settings were grouped by common glacial and soils characteristics where they were linked to predict similar conditions over a wider ranging area. Modifications to their site specific DRASTIC ratings can be extrapolated to the larger geologic regions. All 21 sites were evaluated for their DRASTIC settings and new Ground Water Pollution Potential numbers were assigned where necessary. Modification of the DRASTIC mapping method has made the Ohio Ground Water Pollution Potential mapping program more protective of Ohio's ground water supplies. DRASTIC mapping efforts can play an important role in not only statewide but also local ground water pollution protection efforts.**

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INTRODUCTION

In 1987, the Ohio Department of Natural Resources (ODNR), Division of Water began a Ground Water Pollution Potential mapping program, on a county-by-county basis. This mapping effort was based on the US Environmental Protection Agency (US EPA) DRASTIC model (Aller and others 1987). As this mapping effort proceeded, modifications were made to the original US EPA methodology in order to incorporate additional research information into the scoring system. A history of the Ohio DRASTIC mapping effort and modifications made to the original US EPA methodology is the subject of the paper "DRASTIC Hydrogeologic Settings Modified for Fractured Till: Part 1. Theory" (Weatherington-Rice and others 2006a) also featured in this special issue.

By 1995, the DRASTIC methodology in use by ODNR had been modified to include rapid ground-water recharge in fractured glacial deposits. Weatherington-Rice and others (2000c) discussed research showing that ground-water recharge occurs much more rapidly in fine-grained unlithified glacial deposits than has historically been recognized. This phenomenon of rapid recharge was also discussed by others including Haefner (2000a), Allred (2000), and Fausey and others (2000). On a soils level, Tornes and others (2000) documented 95 soil series where fractures were present.

A study was undertaken by the authors to evaluate DRASTIC ratings in locations where fractured glacial materials have been observed. The purpose of the study was fourfold: 1) to identify the hydrogeologic settings where fracture flow in fine-grained materials was present; 2) to determine if the observed fractured soils had been previously identified by Tornes and others (2000); 3) to determine the effect of the "rapid recharge" fracture modification on DRASTIC indices; and 4) to evaluate the use of DRASTIC settings as a way to predict the existence of fractures in the same or similar hydrogeologic settings in Ohio and beyond. Locations to be evaluated were selected based on the availability of field observations as well as other soil and geologic information. Where available, information such as glacial setting, geologic bedrock lithology, soil series, and an identification of the underlying parent glacial materials were included in the evaluation.

MATERIALS AND METHODS

The first step in the evaluation was to identify sites where documented fractures were present. This effort was begun by reviewing published articles. Sites were chosen for evaluation based on documentation of fractures in the upper zone ranging between the ground surface and six to twenty feet of depth, even though information for depths in excess of twenty feet was available for a number of the selected sites. Some sites contained multiple fine-grained deposits of different Illinoian- and/or Wisconsinan-age glacial advances. Fracturing in the underlying deposits had been documented at most sites. Information for each of the chosen sites was collected by soil borings, backhoe excavations, from fresh surface preparation of natural stream cuts, or a combination of these methods. A total of 21 sites were chosen for evaluation. The county locations for these sites are shown on Figure 1.

Once the sites were identified, each site location was grouped by county. County Soil Surveys and ODNR county-based Ground Water Pollution Potential reports were collected. In counties where no Ground Water

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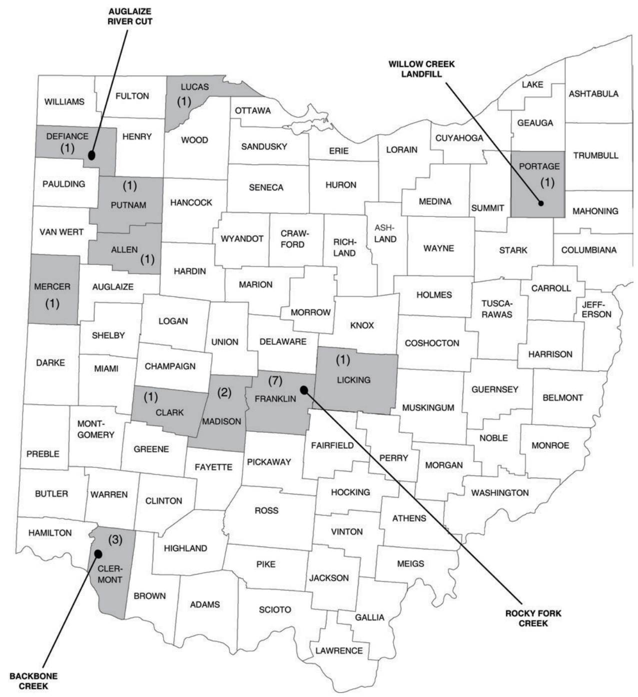


FIGURE 1. Locations of the four featured field observation sites. See Table 1 for the county locations of all 21 sites. Number of sites per county in (#).

Pollution Potential map had been completed, general DRASTIC hydrogeologic settings were developed based on the Quaternary geology as mapped by Pavey and others (1999), the appropriate county Soil Survey, and the Ground Water Pollution Potential reports of similar counties. Where specific knowledge of a site allowed for refinement of the generalized mapping process, additional settings were included to expand upon the mapped hydrogeologic DRASTIC settings.

Data for each of the sites and their respective DRASTIC hydrogeologic settings were tabulated to aid in site comparison and to allow validation of the fractured till modifications to the DRASTIC methodology. Four representative sites were selected for a more detailed discussion. These "featured" sites were chosen not only for their representative hydrogeologic settings but also for the abundant field data that had been collected at each of these sites. Additional documentation such as pictures, publications, report references, and laboratory data on these sites were included in the review, where available. Because much of this information had not been published in peer-reviewed journals, unpublished documents were reviewed, including university theses and dissertation collections, field guides, and public documents in the files of ODNR, US EPA, and the Ohio Environmental Protection Agency (Ohio EPA). Additionally, personal unpublished data were included in identification of fractured conditions.

RESULTS

Eight DRASTIC hydrogeologic settings were identified as containing one or more of the 21 study sites where fractures have been observed. Table 1 lists each of the sites, the eight DRASTIC hydrogeologic settings as they relate to the sites, and supporting literature. In a number of cases, a documented site extended across more than one hydrogeologic setting and, therefore, is listed in all applicable settings. The four "featured sites" in this paper (Backbone Creek Stream Cut, WillowCreek Landfill, Rocky Fork Creek Stream Cut, and Auglaize River Stream Cut) are located within six of the identified DRASTIC hydrogeologic settings. The locations of the featured sites are shown on Figure 1, and conceptual block diagrams of the six hydrogeologic settings are presented in Figure 2. Table 2 provides details about the specific DRASTIC settings for each featured site and identifies whether the pollution potential mapping effort for that county took place before, during, or after ODNR modified DRASTIC mapping for fractured till. Where those modifications produced a different DRASTIC Ground Water Pollution Potential (GWPP) index total, that new index is included. Table 3 lists the individual components of the DRASTIC index for one example featured site, the Backbone Creek Till Cut. More detailed tables and information about bedrock geology, glacial materials, glacial setting, soil type, parent material, and selected DRASTIC texture for all 21 sites included in this study are presented in Weatherington-Rice (2003).

Four Featured Sites

The following sections describe in more detail the four "featured sites" chosen for more detailed evaluation. These four sites have been chosen because they are representative of the geology and soils located in that portion of the state. These sites have been studied through time and are well documented in publications.

Backbone Creek Stream Cut

This stream cut is in Clermont County in southwestern Ohio (Fig. 1). The site can be found on the Batavia, OH, USGS 7.5 minute topographic quadrangle. The Backbone Creek cut is just east of the East Fork Little Miami River, just north of the city of Batavia. The site is mapped on the Clermont County DRASTIC map (Schmidt and others 1994) as 7Aa setting, Glacial Till over Bedded Sedimentary Rocks. While this hydrogeologic setting is appropriate for the greater area (DRASTIC mapping units typically cover 100 acres or more, Aller and others 1987), the specific section that is historically referred to as the "Backbone Creek Cut" could be appropriately remapped 7D, Buried Valley, because of the identification of a thick sequence of sand and gravel, if a more detailed mapping effort is undertaken at some point in the future. A zoomed photograph of one of the upper fracture faces is shown in Figure 3. Teller (1970) made a detailed map of this stream cut, and his study included grain size analysis, pebble counts, and clay mineralogy. Goldthwait and others (1981) also gave a detailed description of the site.

The DRASTIC mapping effort for Clermont County designated the Wisconsinan-age loess over Illinoian-age paleosol and till as a clay loam. The Soil Survey of Clermont County, OH (Lerch and others 1975), mapped the site (found on map sheet #15) as EdG3 Edenton and

TABLE 1

Site information and references.

Site Name/Means of Observation	DRASTIC Symbol[a]	DRASTIC Setting	Site Location	Literature References
Auglaize River, east bank and tributaries, just downstream from the Bryan Hydroelectric Dam (natural cuts)*	7F	Glacial Lake Deposits	Defiance County, Auglaize River south of the city of Defiance, west of Ohio Rt. 66	Forsyth 1960; Flesher 1984
Backbone Creek Till Cut (natural cut)*	7Aa	Glacial Till over Bedded Sedimentary Rocks	Clermont County, North bank Backbone Creek, just east of the East Fork Little Miami River, north of Batavia, Ohio	Schmidt and others 1994; Lerch and others 1975, 2002; Teller 1970; Goldthwait and others 1981; Weatherington-Rice and others 2000 a,b
Bill Moose Run (natural cuts)	7Ae	Glacial Till over Shale	Franklin County, between the Ohio School for the Blind and the Ohio School for the Deaf, between High St. and Indianola Ave.	McLoda and Parkinson 1980; Angle 1995a; Haefner 2000b; Schmidt and Goldthwait 1958
	7D	Buried Valley		
	7Ec	Alluvium over Sedimentary Rocks		
CECOS Hazardous Waste Landfill (borings & excavations)	7Af	Sand & Gravel Inter-bedded in Glacial Till	Clermont County, South of US Rt. 50 between Ownesville & the Clermont/Brown Co. line	Schmidt and others 1994; Lerch and others 1975, 2002; Brockman and others 1998
	7Aa	Glacial Till over Bedded Sedimentary Rocks		
Coldwater Area, private site (borings & excavations)	7Ac	Glacial Till over Limestone	Mercer County, southeast of Coldwater near Chicasaw	Sugar 1989; Priest 1979
Envirosafe Hazardous Waste Landfill (borings & water line trenches)	7F	Glacial Lake Deposits	Lucas County, city of Oregon, Cedar Point and Wynn Roads, just east of Otter Creek	Stone and others 1980; Hallfrisch 2002
Flint Road Cemetery Expansion (excavations)	7Ae	Glacial Till over Shale	Franklin County, West side Flint Rd. between US Rt. 23 and Lazelle Rd.	McLoda and Parkinson 1980; Angle 1995a; Schmidt and Goldthwait 1958
Graessle Road till cut (natural cut)	7D	Buried Valley	Franklin County, east side of road facing tributary to Big Darby Creek, south end of Battelle-Darby Metro Park	Angle 1995a; McLoda and Parkinson 1980; Haefner 2000b; Lloyd 1998; Schmidt and Goldthwait 1958
I-270/Cleveland Ave. Cloverleaf near Westerville (drainage excavation & cut)	7D	Buried Valley	Franklin County, northwest section of cloverleaf, north bank drainage ditch	Angle 1995a; McLoda and Parkinson 1980; Schmidt and Goldthwait 1958
Lobdell Creek Park on Lobdell Creek (natural cut)	7D	Buried Valley	Licking County, north of Alexandria, north of Lobdell Rd., east side of Mounts Rd.	Parkinson and others 1992; Frolking and Szabo 1998; Angle 1995b; Dove 1960; Forsyth 1966
	7Ae	Glacial Till over Shale		
London Correctional Institute (borings)	7Af	Sand & Gravel Inter-Bedded in Glacial Till	Madison County, just west of the city of London on Springfield Road (south of US Rt. 40)	Gerken and Scherzinger 1981; Hallfrisch and Voytek 1987; Lloyd 1998
	7D Revised	Buried Valley		Angle and Barrett 2005a Revised DRASTIC mapping
Marble Cliff Quarries (excavations)	7Ac	Glacial Till over Limestone	Franklin County, Norwich Twp., west of the Scioto River, north of 670, east of Dublin Rd.	Angle 1995a; Haefner 2000b; McLoda and Parkinson 1980; Schmidt and Goldthwait 1958

Table 1 (*Cont.*)

Site information and references.

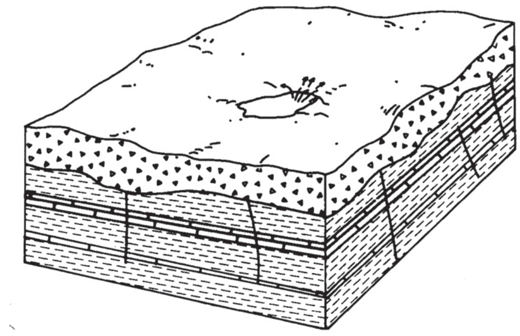
Site Name/Means of Observation	DRASTIC Symbol[a]	DRASTIC Setting	Site Location	Literature References
Miller City Solid Waste Landfill (excavation)	7F	Glacial Lake Deposits	Putnam County, just north of Miller City, northeast corner Ohio Routes 108 and 109	Brock and Urban 1974
Molly Caren Farm Science Review (excavation)	7Af	Sand & Gravel Inter-bedded in Glacial Till	Madison County north of US Rt. 40, bisected by Rt. 38 and I-70, west of Lafayette	Gerken and Scherzinger 1981; Hallfrisch and Voytek 1987; Fausey and others 2000; Christy and others 2000; Christy and Weatherington-Rice 2000
	7J Revised	Glacial Complex		Angle and Barrett 2005a Revised DRASTIC mapping
Overbrook Ravine (natural cut) Parkinson	7Ae	Glacial Till over Shale	Franklin County, just south of Cooke Rd. and west of Indianola Ave. on Overbrook Creek in Columbus	Angle 1995a; McLoda and 1980; Schmidt and Goldthwait 1958
	7D	Buried Valley		
Rocky Fork Creek Till Cut (natural cut)*	7Ae	Glacial Till over Shale	Franklin County, just downstream, southwest of Clark State Road Bridge	Frolking and Szabo 1998; Weatherington1 978; Angle 1995a; McLoda and Parkinson 1980; Schmidt and Goldthwait 1958
	7Ad	Glacial Till over Sandstone	Franklin County, east of Hamilton Road and the city of Gahanna at Rocky Fork Creek	
	7Ad	Glacial Till over Sandstone	Franklin County, just downstream, southwest of Clark State Road Bridge	
	7D	Buried Valley		
Rocky Run, east bank by mouth at Brushy Fork (natural cut)	7Af	Sand & Gravel Inter-bedded in Glacial Till	Clermont County, just upstream of Stonelick Creek, just north of Owensville	Schmidt and others 1994; Lerch and others 1975, 2002
Spencerville, Ohio, Proposed Solid Waste Landfill (borings)	7Ac	Glacial Till over Limestone	Allen County, Spencerville, just east of the village, north of the railroad tracks	Angle and Barrett 2005b; Heffner and others 1965
Tremont Solid Waste Landfill & Hazardous Waste Barrel Fill, proposed Clarkco Solid Waste Landfill, and Amstutz Farm (borings & excavations)	7D	Buried Valley	Clark County, north and west of Tremont City, west side of Mad River Valley between Chapman and Storms creeks, just south of the Champaign/Clark Co. line	Christy and others 2000; Miller 1999; Vormelker and others 1995
	7Ac	Glacial Till over Limestone		
WillowCreek Landfill (borings and strip mine cut)*	7Aa	Glacial Till over Bedded Sedimentary Rocks	Portage County, South of Rt. 224 and north of Petersen strip mine highwall, Atwater Twp., just west of Atwater/Deerfield Twp. line	Angle 1990; Winslow and White 1966; Orton 1884; Ritchie and others 1978.

* = Featured Site
[a] = DRASTIC symbols are national standardized symbols that are abbreviations for uniform DRASTIC settings.
7 = Glaciated Central Ground Water Region

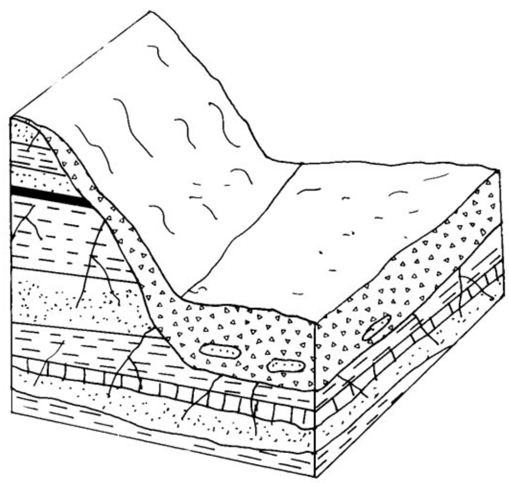
A = Till over some type of sedimentary bedrock
D = Buried Valley
E = Alluvium
F = Lake Deposits

Fairmont soils and HkF2 Hickory loam. However, the soils exposed at the Backbone Creek cut are not the Edenton and Fairmont soils series, but rather are part of the Hickory loam inclusions included in that more generalized mapping unit. This evaluation was confirmed by Timothy Gerber, State Soil Scientist, ODNR, Division of Soil and Water in a meeting held in July 2002 to discuss this issue. The identification of massive

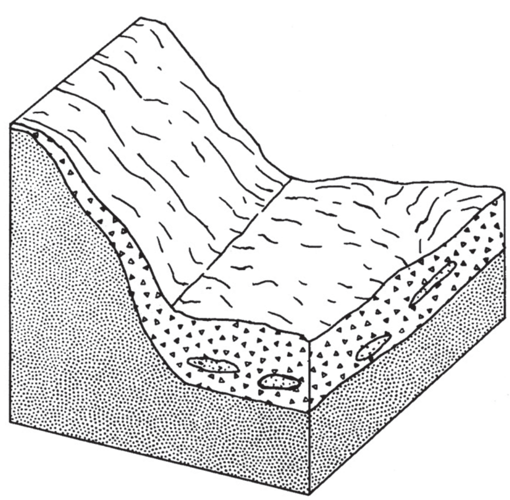
7Aa: Glacial Till over Bedded Sedimentary Rocks (depicting the setting at Backbone Creek)



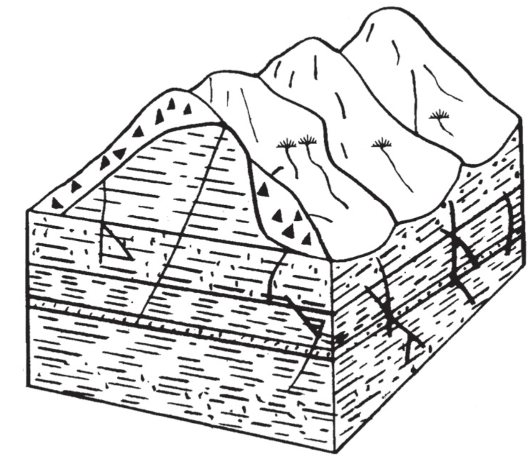
7Aa: Glacial Till over Bedded Sedimentary Rocks (depicting the setting at WillowCreek Landfill)



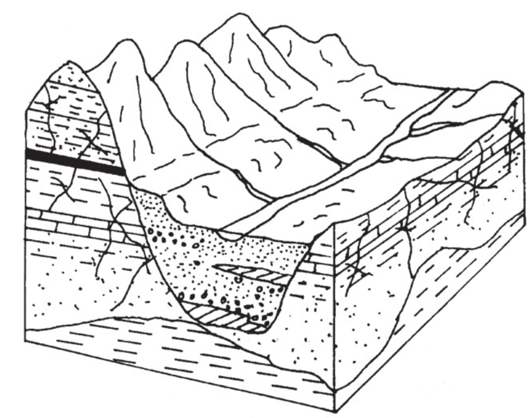
7Ad: Glacial Till over Sandstone (depicting the setting at Rocky Fork Creek)



7Ae: Glacial Till over Shale (depicting the setting at Rocky Fork Creek)



7D: Buried Valley (depicting the setting at Rocky Fork Creek)



7F: Glacial Lake Deposits (depicting the setting at Auglaize River)

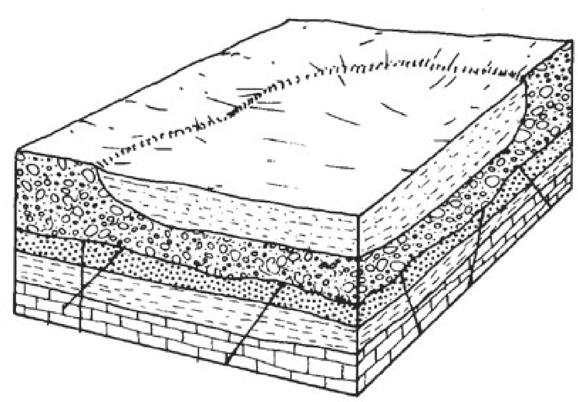


FIGURE 2. DRASTIC hydrogeologic settings at the four featured field observation sites (from Angle 1990, 1995a; Miller and Angle 2002; Schmidt and others 1994).

TABLE 2

Comparison of old versus modified DRASTIC ratings for the featured sites.

Site Name	County (Location)	DRASTIC Setting	Pre- or Post-DRASTIC Modification	DRASTIC Symbol[a]	Old DRASTIC Number	New DRASTIC Number
Backbone Creek Till Cut	Clermont	Glacial Till over Bedded Sedimentary Rocks	Pre-modification	7Aa2	86	103
WillowCreek Landfill	Portage	Glacial Till over Bedded Sedimentary Rocks	Pre-modification	7Aa70	127	132
Rocky Fork Creek Till Cut	Franklin (at Clark State Road Bridge)	Glacial Till over Sandstone	During modification	7Ad2 7Ad11	123 115	128 120
	Franklin (at Hunt Club Cut)	Glacial Till over Sandstone	During modification	7Ad10 7Ad11	112 115	117 120
	Franklin (Bedford Shale Section)	Glacial Till over Shale	During modification	7Ae8	103	108
		Buried Valley	During modification	7D77 7D78	152 131	152 136
Auglaize River, east bank and tributaries, just downstream from the Bryan Hydroelectric Dam	Defiance	Glacial Lake Deposits	Not Completed	7F	*	*

* = Mapping for these counties are not completed.
[a] = DRASTIC symbols are national standardized symbols that are abbreviations for uniform DRASTIC settings.
7 = Glaciated Central Region
A = Till over some type of sedimentary bedrock.
D = Buried Valley
E = Alluvium
F = Lake Deposits

polygonal prismatic fractures with calcite coatings at the top of the Backbone Creek cut (Fig. 3) supports the inclusion of Hickory loam as a soil with a fractured subsolum. Therefore, this site confirms the observations by Tornes and others (2000) that the Hickory loam exhibits fractures.

The Clermont County DRASTIC study predates the 1995 modification of the DRASTIC rating system that incorporates the influence of fractures on ground water pollution potential. If the site is evaluated using the modified rating system, the "Net Recharge" value is increased from 2.0 to 4.0 inches (with an associated rating of 3) to a range of 4.0 to 7.0 inches (with an associated rating of 6). Similarly, the "Impact of the vadose zone" range for silt/clay is raised from 4 to 5. With these adjustments, the GWPP Index increases by 17 points from 86 to 103. This increase moves the Backbone Creek DRASTIC setting from the lowest range in Clermont County of 80 to 99 points to the lower end of the next range of 100 to 119 points. While this is not a "high" GWPP Index value, the modification of these two parameters, documented in Table 3, raises the site to the next vulnerability range. If the specific site is reevaluated to take into consideration the water-bearing properties of the thick sand and gravel unit found at the base of the cut, the GWPP index is even higher.

WillowCreek Landfill

The WillowCreek solid waste landfill is located in Atwater Township, Portage County on the Deerfield, OH, 7.5 minute USGS topographic quadrangle. The site is shown as a former coal strip mine at the junction of map sheets numbers 58 and 59 of the Soil Survey of Portage County, OH (Ritchie and others 1978). Like the Backbone Creek cut in Clermont County, this site is also mapped within the hydrogeologic setting 7Aa, Glacial Till over Bedded Sedimentary Rocks. The underlying bedrock is the Pennsylvanian-age Pottsville Formation and the cap rock north of the strip mine is the Homewood Sandstone. Pavey and others (1999) map the glacial deposits at the site as Late Wisconsinan – Late Woodfordian (18 to 14 KA) ice-deposited units, clayey Hiram Till, ground moraine, flat to gently undulating.

The site study area is south of US Rt. 224 and north of the strip mine's north high wall. The old WillowCreek Landfill, now in closure, is located in the old Petersen Coal Co. strip mine, in Atwater Township, on the Atwater/Deerfield Township line, just south of Rt. 224. As part of the landfill closure process, a series of monitoring wells were installed at the site under an

Table 3

Features, ranges, ratings, and indices for example site (Backbone Creek) showing change in DRASTIC index.

DRASTIC components and their values (for DRASTIC symbol 7Aa2)							
		Range		Rating		Index	
Feature	Weight	Previous Value	New Value (if changed)	Previous Value	New Value (if changed)	Previous Value	New Value
Depth to Water	5	5 to 15	–	7	–	35	35
Net Recharge	4	2 to 4	4 to 7	3	6	12	24
Aquifer Media	3	Interbedded Lime-stone & Shale	–	3	–	9	9
Soil Media	2	Clay Loam	–	3	–	6	6
Topography	1	18+%	–	1	–	1	1
Impact of Vadose Zone	5	Silt/Clay	Till	4	5	20	25
Hydraulic Conductivity	3	1 to 100	–	1	–	3	3
Total GWPP Index:						86	103

agreement between Browning Ferris Industries (BFI), the owner of the landfill at that time, and the Portage County Solid Waste District. Fractures were found in the *in situ* materials during the drilling process (Fig. 4).

The current northern high wall of the old strip mine exposes a series of deposits of Late-Wisconsinan-age tills that overlie the Homewood Sandstone, Bedford Coal, and the Upper, Middle, and Lower Mercer members which include coals, sandstones, shale, and limestones sequences. All of these bedrock units are parts of the Pottsville Formation. Fractures were observed in both the *in situ* tills exposed in the high wall and in split spoon samples collected during the drilling of the monitoring wells on the north side of the landfill.

The Soil Survey of Portage County, OH (Ritchie and others 1978), maps the *in situ* soils north of the high wall as Remsen silt loam (Rm) with both A and B slopes. This soil is noted to have a silty clay "C" horizon. The DRASTIC soil texture rating for the substratum is a clay loam. The identification of fracturing at the WillowCreek further confirms the presence of fractures in the Remsen silt loams.

Figure 3: Zoomed photograph of calcite and iron staining on polygonal fracture face at Backbone Creek cut. Exposure due to collapse of a large, well developed soil polygon approximately 5.0 m (15 feet) high. (Photo by J Weatherington-Rice)

Portage County was the earliest of the four featured sites to be mapped using DRASTIC (Angle 1990) and, therefore, predated the modification of the DRASTIC scoring system to accommodate fractured settings. The site was assigned a GWPP Index number of 127. This number places the location in the Index Range of 120 to 139. A review of the DRASTIC settings in Table 3 indicates that if the site is mapped using the modified DRASTIC scoring system that only the "Till" designation for "Impact to the Vadose Zone" needs to be reevaluated, and assigned a rating of 5 instead of a 4. When multiplied by the weighting factor for the Vadose Zone (5), the additional five points increases the GWPP Index to 132. The resultant GWPP is still within the range of 120 to 139.

The strip mine, one of the last strip mines mapped under the DRASTIC program (which no longer gives a value to disturbed materials), was mapped as 7G1, Thin Till Over Bedded Sedimentary Rock and assigned a GWPP Index rating of 157. A value of 157 is just three points below the cutoff point for the next vulnerability range of 160 to 179. The DRASTIC index range of 160 to 179 traditionally, has been interpreted as being moderately vulnerable to vulnerable. The fill materials used as daily and final cover at the landfill are the subject of another paper in this issue by Weatherington-Rice and Hall (2006).

FIGURE 4: Vertical fractures in core of *in situ* Kent till taken at WillowCreek Landfill. Note calcium carbonate deposit on fracture face. (Photo by J Weatherington-Rice)

Rocky Fork Creek Stream Cut

The Rocky Fork Creek stream cut is located in Jefferson Township and the city of Gahanna in Franklin County. The site can be found on the New Albany, OH, 7.5 minute USGS topographical survey map. Located on map sheet number 26 of the Soil Survey of Franklin County, OH (McLoda and Parkinson 1980), the Rocky Fork Creek stream segment can be found on the eastern half of the map sheet, from Clark State Road to Hamilton Road. As the stream transects this section of eroded high bluffs, three different hydrogeologic settings are encountered. They include: Glacial Till over Sandstone, Buried Valley, and Glacial Till over Shale.

The stream cut of Rocky Fork Creek is among the most complex set of hydrogeologic settings considered for this paper. Covering not only two different types of sedimentary bedrock with significantly different hydraulic properties (sandstone and shale), but also crossing a pre-glacial or inter-glacial valley with buried sands and gravels, the settings display different potentials for ground-water contamination. Photos taken from ODNR Division of Geological Survey historical files document the progression of the Rocky Fork Creek till cut over time. Figure 5 shows the Bedford Shale western limit to the buried valley cut.

Frolking and Szabo (1998) archive the active history of the site, list relevant publications, and present a glacial description of the buried valley section of the cut. This guidebook lists summaries of laboratory data on grain size, calcium carbonate mineral content, pebble counts, and clay mineralogy for the tills.

Although Rocky Fork Creek traverses different hydrogeologic settings, a common factor among the settings is the overlying glacial deposits. The stream cut is mapped as Late Wisconsinan – Late Woodfordian (18 to 14 KA) ice-deposited units, silty loam till (Darby till), ground moraine, flat to gently undulating by Pavey and others (1999). The Darby till is fractured relatively uniformly along the entire cut. Where the underlying Caesar till is exposed, particularly in the buried valley, that till is also fractured. Frolking and Szabo (1998) quote Fernandez and others (1988) as having observed "some sand filled joints of undetermined origin" in the upper portions of the oldest Gahanna or Rocky Fork till, now thought to be of Illinoian age, and therefore comparable to the upper Rainsboro till of the Backbone Creek cut in Clermont County.

The Soil Survey of Franklin County, OH (McLoda and Parkinson 1980), identifies three soils at the site, the AdD2 and AdE2 Alexandria silt loam, the BeB Bennington silt loam, and the CaB Cardington silt loam. Angle (1995a) maps all three soils with a DRASTIC texture of

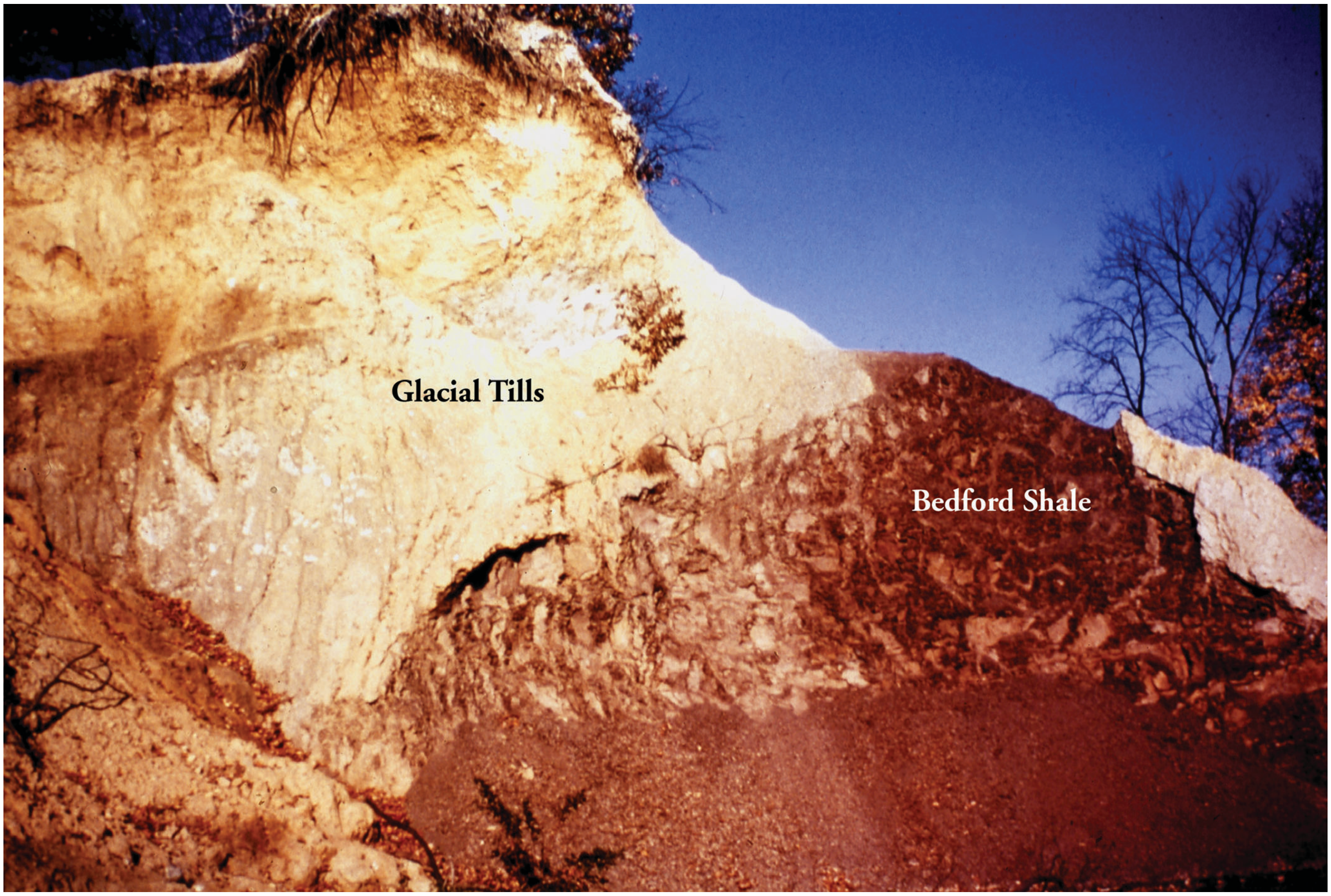


FIGURE 5: Rocky Fork Creek west end of cut, till over Bedford Shale. (Photo by P Smyth, Ohio Geological Survey files, 1951)

clay loam.

The Ground Water Pollution Potential of Franklin County, Ohio (Angle 1995a) was evaluated during the modification process for the DRASTIC mapping system. To incorporate the fracture modification to the DRASTIC scoring system, the ratings for the "Impact of Vadose Zone" need to be increased from 4 to 5. This is true for all settings except 7D77, which already has a rating of 5 and a total GWPP index number of 152. If the range is increased by a factor of one and then multiplied by the appropriate weighting factor, the result is an increased GWPP index for these settings (Table 2, Fig. 6). The corrected values for the GWPP range from 108 for setting 7Ae8 over the Bedford Shale to the high of 152 (for 7D77) over the sand and gravel aquifer in the buried valley where the "Soil Media" was classified as a "silt loam." Raising the GWPP index number by five points changes 7Ad11 from 115 to 120. This change places this setting in the next higher index range of 120 to 139. Adjustments to 7Ad5 also cause this setting to move to the 120 to 139 range.

The significance of changing ranges is that ODNR uses different colors to display different index ranges. The color-coding allows the viewer to quickly assess the relative vulnerability of the area to ground-water pollution. By changing these settings to the next index range, the map of pollution potential in the area for the inside curve of land from Clark State Road to Hamilton Road looks markedly different and, therefore, has a major impact on the color display of the eastern portion of the city of Gahanna. Figure 6A shows the original DRASTIC GWPP indices as published in Angle (1995a) for the settings of 7Ad5 and 7Ad11 in the vicinity of Rocky Fork Creek. Figure 6B shows the visual effect created when the map is re-colored to reflect the modified DRASTIC indices for these two settings.

Auglaize River Stream Cut

The Auglaize River stream cut is located in Defiance Township of Defiance County on the east side of the river downstream from the city of Bryan's hydroelectric dam. The cut was a field stop for the Ohio Fracture Flow Working Group's 2001 Northwest Ohio Field Day. The cut is mapped on the Junction, Ohio 7.5 minute USGS topographic map. It can be located on map sheet 56 of the Soil Survey of Defiance County, OH (Flesher 1984). The dam is clearly marked in the center of the map sheet. The escarpments are shown in sections 10 and 3 on the top half of the sheet. Other escarpments are noted along the river and tributary streams, which also may have fractured settings if explored.

The Auglaize River stream cut is a mapping effort in progress. Although Forsyth (1960) discussed the site in "Correlation of Tills Exposed in Toledo Edison Dam Cut, Ohio" and the Soil Survey was published in 1984, Defiance County does not yet have a Ground-Water

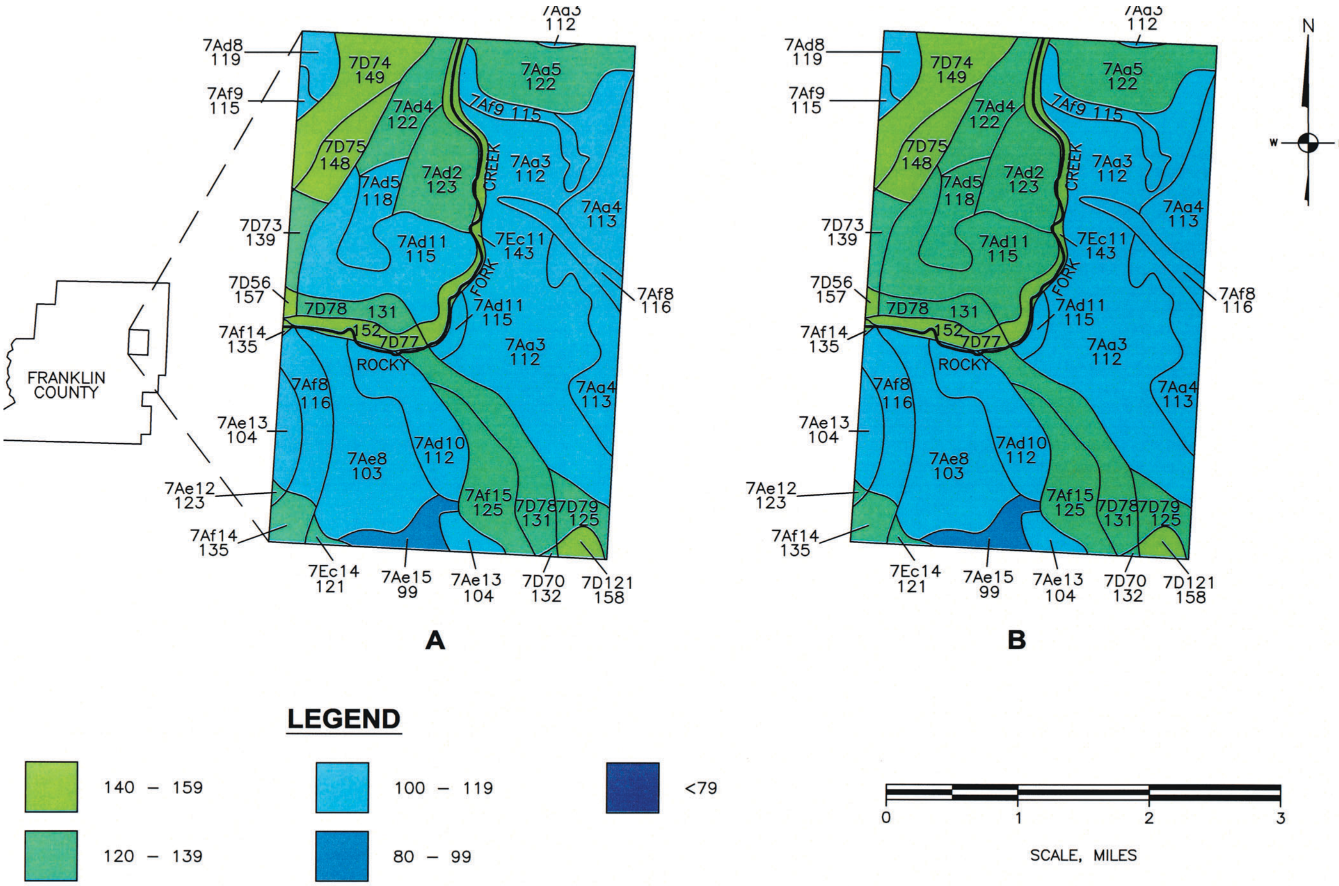


FIGURE 6. DRASTIC maps for Rocky Fork Creek site showing (A) original GWPP indices (Angle 1995a) and (B) modified indices for fractured till.

Pollution Potential map completed or under way. Without a completed assessment, it is not possible to provide a DRASTIC GWPP Index for the site. It is possible, however, to designate a DRASTIC hydrogeologic setting for the site based on comparisons with neighboring Henry County, which has a completed DRASTIC map (Miller and Angle 2002). The escarpments along the east bank of the Auglaize River are capped with lacustrine deposits. The escarpments were assigned to 7F Glacial Lake Deposits.

Pavey and others (1999) map the site as Late Wisconsinan (23 to 13 KA) waterlain units, mostly laminated lacustrine clay, deposited in calm water of glacial lakes, covered in places with thin organic deposits. Forsyth (1960) noted a 0 to 5 foot deposit of alluvium, thicker to the south, over a 3 to 5 foot deposit of leached lake silts at the site, which is locally poorly laminated and thicker towards the north end of the cut. It is these alluvial and lacustrine materials that provide the parent materials for the Fulton loam and St. Clair silty clay loam that have formed in the area. The two tills here exposed are the Late Wisconsinan contributions to glacial deposits in northwestern Ohio. When visited in October 2001, extensive fracturing in both of the tills was observed by the authors (Fig. 7).

Forsyth (1960) also summarizes the dates of the Wisconsinan advances and retreats from the radiocarbon dates that had been collected up to that time. As such, this is an excellent companion paper for Frolking and Szabo (1998) who present a similar summary in their field guide.

The Soil Survey of Defiance County, OH (Flesher 1984), indicates a "C" horizon texture for the Fulton loam of silty clay, clay, and silty clay loam. The St. Clair silty clay loam has clay, silty clay, and clay loam textures in the lowest horizon. The DRASTIC "Soil Media" designation for these soils is shrink-swell clay, based on the shrinking and swelling properties of the clay mineral matrix.

DISCUSSION

This paper describes conditions at only 21 sites, but the conditions described are much more regional in nature. Given the common characteristics between those sites and the areas surrounding them, it is possible to extend the boundaries of these fractured conditions to other sites. For example, the conditions of the Rocky Fork Creek sites can be related to Overbrook Ravine, Bill Moose Run, the Flint Road Cemetery expansion, and the I-270/Cleveland Ave. cloverleaf, which have soils, bedrock, and glacial histories in common. These sites are located over Devonian-age Ohio Shale and Early

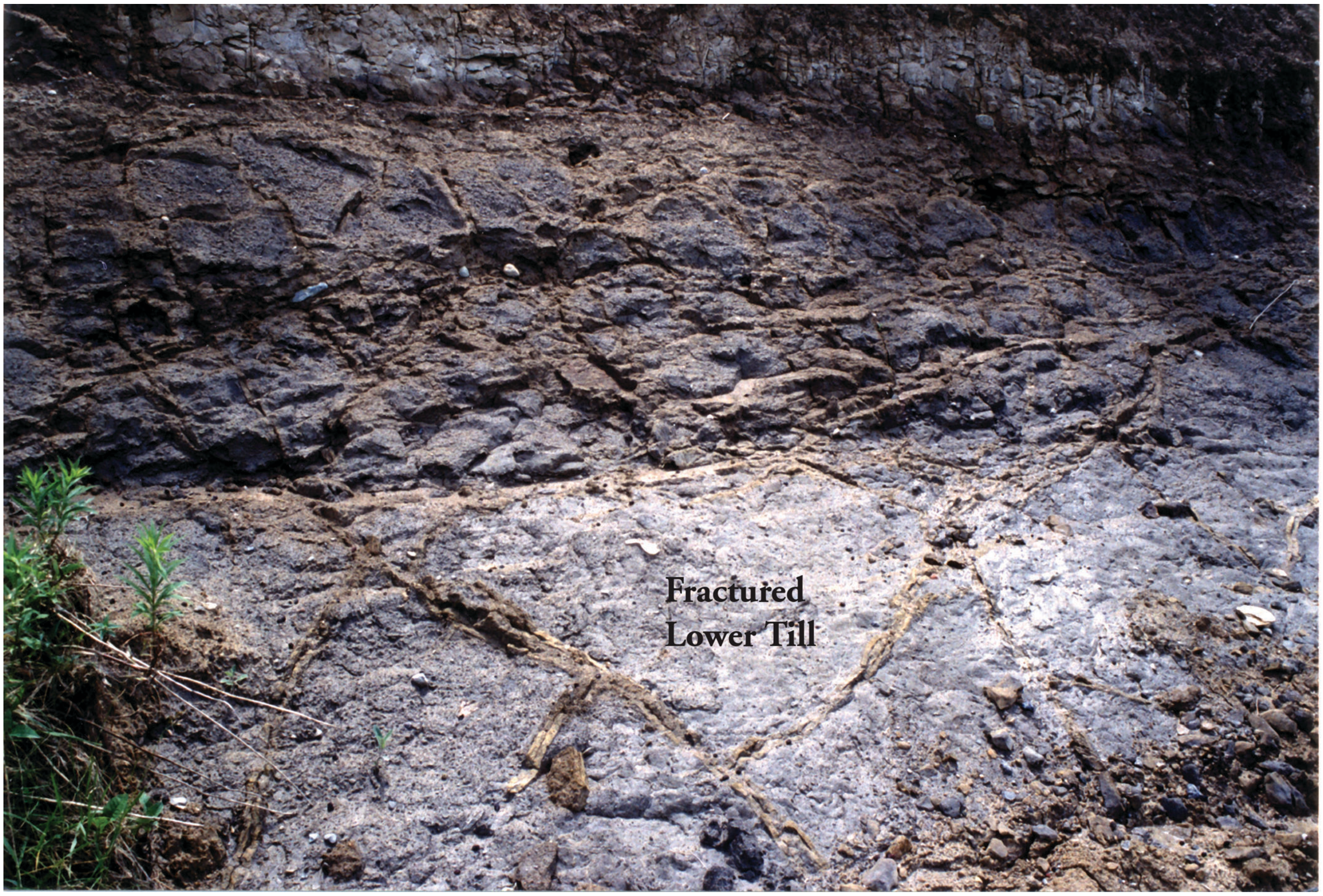


FIGURE 7: Two fractured tills with possible paleosol in between, east bank Auglaize River cut just downstream from the city of Bryan hydroelectric dam. Close-up of possible paleosol and lower till. Note more resistant remineralization infilling in the lower till and paleosol. Fractures are still hydraulically active. (Photo by L Aller 2003)

Mississippian-age Bedford Shale and Berea Sandstone. The bedrock formations are low lime and the resulting glacial tills and soils are also lower in lime than those found west of the Columbus and Delaware Limestone/ Ohio Shale contact. The common soils are Alexandria, Bennington, and Cardington, which are important soils in eastern Franklin County as well as in surrounding counties to the north, east, and south of Franklin County. The identification of fractures at each of these sites gives support to the DRASTIC mapping of fractures in the region surrounding these sites.

Another set of related sites are the Amstutz farm in Clark County, the two Madison County sites, London Correctional Institute, The Ohio State University's Molly Caren farm, and the two western Franklin County sites: Graessle Road and Marble Cliff Quarries. The common Silurian and early Devonian limestones and dolomites produce high lime tills that develop through time into the Miamian, Celina, Crosby, Lewisburg, and Kokomo soils common to these sites. Because all these sites have fractured tills, these observations support modification of the DRASTIC settings that are found in the older Clark and Madison county reports. A new revision of the Ground Water Pollution Potential map and report for Madison County has recently been compiled using the new understanding of fractures in glacial tills (Angle and Barrett 2005a). Ratings for the glacial till vadose zone media for both the above mentioned sites in Madison County increased due to the fractured nature of the till (Angle and Barrett 2005a).

A third grouping can be seen in western Ohio at the Coldwater area site in Mercer County and the Spencerville site in Allen County. These sites are Late Wisconsinan-age high lime tills that have formed over Silurian-age limestones and dolomites, but these tills are post-Erie Interstadial and are finer-grained than those found in the central part of the state. Here, the common soils are Blount and Pewamo.

Backbone Creek in Clermont County shares Hickory loam soils with Rocky Run. The CECOS site, which has less relief than the two stream cuts, supports the formation of different soils, but the bedrock formations and the depositional sequence of Wisconsinan-age loess over Illinoian-age glacial till is the same.

The Auglaize River site in Defiance County, the Envirosafe site in Lucas County, and the Miller City site in Putnam County also share common settings. These sites are located in lacustrine deposits over Late Wisconsinan-age, post-Erie Interstadial, high lime till. While the soils are not necessarily the same, the common soils overlap. Fulton soils are found at two sites: the Auglaize River site and the Envirosafe site. Latty clay and Toledo soils are found at both the Envirosafe site in Lucas County and at the Miller City site in Putnam County. These fractured sites represent the post-glacial lacustrine deposits in northwest Ohio.

These 21 glacial sites confirm the presence of fractures in 23 of the soils listed in Tornes and others (2000) and identify four new soils as fractured: Amanda, Avonburg, Blanchester, and Clermont. However, even though only 27 soils were evaluated, these 27 soils constitute a significant area of the counties where these hydrogeologic settings were located (Weatherington-Rice 2003).

Summary and Conclusions

These 21 glacial sites include most of the major DRASTIC settings found in glaciated Ohio, thus adding support for the ODNR decision in the mid-1990s to modify the DRASTIC ranking system by incorporating a fine-grained fracture component into the ground water pollution potential index number. Through this modification, the relative vulnerability of Ohio's ground water is better characterized.

From the beginning, the DRASTIC authors recognized the need to protect the buried valley coarse-grained sand and gravel deposits. Those units provide much of Ohio's municipal and industrial ground-water supplies. But the water supply for most of rural Ohio is not from major buried valley aquifers. Rural Ohio traditionally obtains ground water either from the sand and gravel lenses found in Ohio's glacial tills or from the underlying bedrock. The recharge to those systems is typically through finer-grained materials—materials that have now been established to be fractured in many hydrogeologic settings. It is the fractured nature of these finer-grained materials and the relatively rapid water movement through these fractures that increases the vulnerability of the aquifer to ground water contamination. That vulnerability has now been acknowledged by the ODNR-led modification to the DRASTIC ranking system, and is now being incorporated into the county-based Ground Water Pollution Protection mapping program.

This paper addresses sites that are located throughout the glaciated portion of Ohio. DRASTIC mapping, like the soil survey process, is a dynamic effort which undergoes continuous improvement. Each time a new county map is developed, those involved in the mapping effort know more and can refine the accuracy further. However, just because a county has an older Ground Water Pollution Potential map and pollution potential index does not mean that the map is not a valid document. DRASTIC maps, coupled with county soil surveys and the other ODNR Divisions of Water and Geological Survey maps, are important basic documents available to local decision makers.

The protection of Ohio's water supplies, both surface and ground, should be one of the major initiatives for the whole state. Water is one of Ohio's greatest resources. By understanding the potential for ground-water contamination in an area, local decision makers can make land-use choices that will preserve both the quality and the quantity of that water supply.

The DRASTIC mapping program continues to undergo refinement as new soils and geologic discoveries are made. This is an iterative process that benefits from the continued input from relevant sciences, related fields of engineering, local government, planners, and the law (Weatherington-Rice and others 2006b). Field geologists and soil scientists working in Ohio for over a century made these discoveries of fractures in Ohio's fine-grained parent materials and have parlayed their implications to further ground-water protection. Only a holistic approach on all levels and a multitude of dedicated experts in all the relevant fields can achieve ground-water quality protection. The DRASTIC mapping process that incorporates modifications for fracture flow is a major step towards that goal.

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